Analysis of combustion performance of non-conventional syngas in mGT combustor: Assessment of the impact of the quality on flame stability and emissions

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Introduction

Worldwide electricity consumption is still increasing [1] while there is the ambition to reduce greenhouse gas emissions. To ensure sufficient energy resources for our society, an energy source diversification is necessary. Non-conventional renewable resources like biogas, syngas and biofuels are good candidates to achieve these energy mix goals, especially in a decentralized power production context, e.g. when used in micro Gas Turbines (mGTs). To ensure full fuel flexibility on a larger scale, high efficiency and versatile energy conversion must be achieved. To this end, better characterize of non-conventional energy sources in their combustion behavior when used in these mGTs is needed. In order to stress the flexibility of mGTs while achieving stability of the combustion, we performed numerical simulations of an actual 3D combustor model under equivalent thermal power input of syngas fuels compared to the reference case using natural gas as fuel.
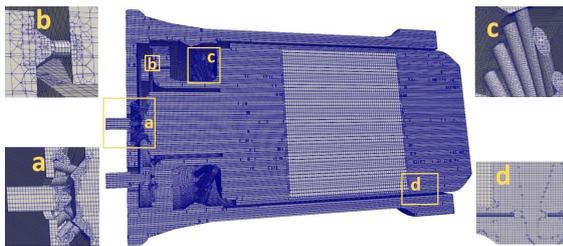
Numerical set-up and methodology

Figure 1: Cross-section of T100 combustion chamber, presenting the applied 3D mesh using 4.3 million cells, including pilot mesh refinement (a), main flame injectors (b), Air swirlers (c) and dilution holes (d).

The combustion chamber, considered in this study, is a reverse flow tubular combustor (Figure 1)[2] . NO_x emissions are controlled by means of a highly air-diluted lean premixed combustion process, leading to low combustion temperature. The fuel is injected using two different lines: the pilot line using 6 nozzles (diffusion flame) and

the main line, composed of a toroidal chamber where injecting is assured by means of 15 nozzles (premixed flame). The pre-heated air from the recuperator, entering the combustion chamber in countercurrent with the flame, is divided over different sections: The swirlers 1 (12 jet holes) provide the air to the pilot flame (approximately 2.5 %) while swirlers 2 (15 radial vanes) and 2' (30 jet holes) supply the air for the main flame (respectively 24.9 % and 12.5 %). Additionally, the remaining part of the incoming air (60.1 %) is passing through nine dilution holes to reduce the temperature of the flue gases to limit the TIT to 950 °C.

Table 1: Boundary and inlet conditions of the simulated cases — inlet Fuel: T_{fuel} = 288 (K) — inlet Air: $\dot{m}$ = 690 (g/s), T_{air} = 865 (K)

		Case a	Case b	Case c
Pilot Fuel	Species	CH_4	Syngas	
	$\dot{m}$	0.8 (g/s)	2.8 (g/s)	
Main Fuel	Species	CH_4	Syngas	Syngas +20% H_2O
	$\dot{m}$g/s	5.7 (g/s)	28 (g/s)	31 (g/s)

To characterize the flow in the combustion chamber, a first numerical simulation has been carried out (See Table 1, Case a), using pure methane injection in the T100 at full load conditions of 100 kW_e. The air distribution ensures a sufficient excess air throughout the combustion. The air mass flow rate was determined based on previously validated thermodynamic cycle analysis [3], whereas the main and pilot fuel injection was set similar to the settings used by De Santis et al [4]. This case corresponds to the actual Turbec T100 mGT operation at nominal conditions and is thus consider the reference case, used to validate the model as well, considering the multitude on numerical and experimental available data on this burner. In the second case (Table 1, Case b), both pilot and main flame are fed with the same Syngas (without steam). To maintain the thermal input power (330 kW) constant, the same adaptation to the lower LHV of the synthesis gas in the pilot and main flow rates has been set, while all other boundary conditions being equal to the reference case. Finally, for Case c) (Table 1), the main flame is fed with untreated Syngas (with additional

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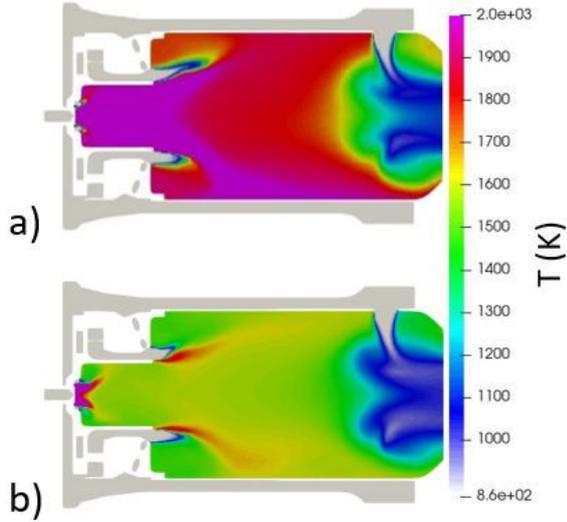Email address: jeremy.bompas@umons.ac.be

Figure 2: Temperature field of cases using Pure methane (Case a) and full Syngas (Case b) for both pilot and main flame

Table 2: CO and NO_x Exhaust gas composition (ppmv), average outlet temperature and peak temperature for the considered cases (*stoechiometric 0D calculations - **De Santis et al. [4] - ***Manufacturer data [5]

Case	a	Ref.	b	c
Pilot Fuel	CH_4		Syngas	
Main Fuel	CH_4		Syngas	Syngas 20% H_2O
LHV (kJ/g)	50.1		10.8	9.8
CO (ppmv)	3	3** < 6***	0.4	0.3
NO_x (ppmv)	11	9** < 15***	3.5	3.1
T_{out} (K)	1333	1331***	1193	1184
T_{max} (K)	2507	2501**	2448	2444

20 % steam mass fraction). The mean LHV of syngas containing high steam fraction imposes to proportionally increase the respective main fuel injection flow rates following the constant thermal power input logic, set up in the previous simulations, even further, as indicated in Table 1.

Results

Within this study, we focused first on the main quantities of interest, being temperature field and global flue gas composition, aiming at validating the reference case (case a), as well as studying the impact of altering progressively the type of fuel. Combustion under nominal operating conditions using pure methane (case a), leads to typical temperature field (Figure 2) similar to those found in literature, e.g., De Santis et al. [4]. Moreover, the temperature peaks, related to the pilot and main flame and reaching a value of T_{max} = 2507 (K), are also well captured, when compared to De Santis et al. [4] where the maximum adiabatic flame temperature found was 2501(K). Moreover, the exhaust gas composition of case a), presented in Table 2, correspond to equilibrium calculations for the main species, i.e., O_2, N_2, CO_2 and H_2O.

Case b), using Syngas to fuel both pilot and main flame, allowed to validate the possibility to fully replace traditional Natural gas by Syngas. The flame ignites effectively and is finally stabilized in the chamber. The flame temperatures are largely decreased in the primary flame chamber by using Syngas (see Figure 2), with a further dilution effect, a lower outlet temperature and substantial NO_x emissions reduction as result. The analyse of the temperature field highlights the diluting effect of Syngas leading to reduce mean outlet temperature from 1333 (K) (Pure methane case a) to 1193 (K) (Syngas case b) and NO_x emissions from 11 (ppmv) to 3.5 (ppmv) (see Table 2).

The increase in syngas steam fraction (+ 20%) in the main flame for case c), with an increasing main fuel mass flow rate of 11 %, does not modify the dynamic behavior in the combustor chamber. The temperature is not significantly influenced by the steam dilution in the Syngas (Table 2). Global chamber temperature, outlet flue gases temperature and NO_x emissions are significantly lower, compared to the reference case (case a), due to the 520% dilution of the fuel flow rate for an equal power input. Similar syngas and natural gas carbon monoxide levels indicate that the combustion efficiency is not significantly affected by the use of clean or even untreated syngases (Table 2).

Conclusion

The aim of our work was to identify the combustion behaviour of a characteristic syngas in a typical industrial combustor to test the versatility of using a wide range of fuels and the flexibility of mGT in the cycle of an efficient CHP at full load conditions. We presented numerical simulations performed on the Turbec T100 combustor, originally fed by natural gas and replaced by a synthesis gas with a progressive steam fraction integration, aiming at studying its impact on emissions and combustion stability. Besides energy source diversification environmental aspects, using syngas is promising on combustion process by lowering temperature in the combustion zone and consequently reducing NO_x while maintaining reasonable CO emissions. It is found that a significant steam fractions in synthesis fuel does not affect the stability of the flame. However, further numerical simulations must be carried out to evaluate the performance of the combustion chamber when also the pilot flame is fed with not fully post-treated syngas altered by important steam fraction, towards emissions and flame stability. Moreover, the impact of pilot/main flame fuel distribution towards flame stability and emissions will be studied as well.

References

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